Mapping coastal landforms and environments in the central sector of Gallocanta saline lake (Iberian Range, Spain)

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Abstract

Gallocanta Lake (NE Spain), with a high ecological value, is the largest and best preserved saline lake in Western Europe. The aim of this study is to map the landforms developed in the margins of the central sector of Gallocanta Lake, at adequate scale for the study of soils and habitats, which is needed for the delineation, management and protection of the wetland. Photointerpretation was combined with topographical, geological, and satellite data in a geographical information system. This study, applied in two selected areas of the central body of the lake, allowed the identification of contrasting landforms and processes in the lake margins. The southern margin, which receives most part of the fluvial materials in the zone exhibits coastal progradation by means of barrier-island generation and sedimentation in the resulting coastal lagoon, a process that can be inferred from the map presented in this work and was confirmed by comparison of aerial photographs taken in different decades. On the margin with virtually no sediment supply coastal erosion and shoreline retreat prevail. In summary, coastal landforms are a result of a complex combination of fluvial and lacustrine processes operating during high and low water level periods.

Keywords: lake geomorphology; mapping; saline lake, saline soils; wetland.

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Introduction and setting

The Gallocanta Depression (Fig. 1), in the Iberian Range (NE Spain), is a closed basin with a catchment area of about 550 km^2. The basin, at about 1000 m.a.s.l., is elongated in NW-SE direction, parallel to the two mountain ranges bordering the basin, Sierra Santa Cruz to the NE and Sierra Caldereros to the SW, whose summits range between 1400 and 1500 m. a.s.l. These mountain ranges are formed by Palaeozoic and Lower Triassic sedimentary rocks and flank an extensive fault-bounded outcrop of deformed Mesozoic rocks.

Climate is semiarid, with rainfall ranging between 650 and 320 mm per year (Gracia, 1990). Winters are long and cold, with average temperature under 5ºC, exceeding 40ºC in summer. Regional winds blow from the NW and W and can often reach velocities of 100 km/h, being responsible for the generation of waves and water currents in the lake (Gracia, 1990).

The Gallocanta Depression has been interpreted as a border-polje or semi-polje (Gracia et al., 2002) whose origin and evolution is related to the karstification of Jurassic limestones in the central part of the basin during Quaternary times. The corrosional deepening of this area continued until the underlying Upper Triassic impermeable materials (clays and evaporites) which, due to the prevalent groundwater recharge, are responsible for the high salinity recorded in the lake waters, especially during summer low-water periods due to high evaporation rates. The polje deepening led to the segmentation of the depression bottom into several disconnected minor poljes (Gracia et al., 2002), with the largest one being occupied by the current Gallocanta Lake, probably since Upper Pleistocene times (about 12,200 yr BP, according to numerical dates presented by Burjachs et al., 1996).

Quaternary alluvial fans have developed on both margins of the depression, with the southern fans being much larger (> 8 km) than the northern ones (up to 1.5 km). Short, steep and intermittent streams flow into the NE margin of the lake, and a larger more permanent stream flows into the lake on the southern margin.

Fig. 1

The present lake has an irregular morphology elongated in the NW-SE direction, with maximum length of 7.7 km and maximum width of 2.8 km. Lake shores are mainly formed by fine-sand, low-gradient beaches, which in some places receive lateral vadose water supplies and are then covered by dense wetland vegetation. To the S and SE, a continuous series of wave-generated micro-cliffs (< 2 m high) limit the central lake sector.

The study area has a high ecological value and is included in the Ramsar Convention international list and the Natura 2000 Network. Current management plans limit uses and activities in the lake surroundings and promote its protection and habitats conservation.

In this study the geomorphological map of a selected area of the lake which shows a rich variety of transitional morphologies and environments from emerged areas to littoral zones, where agricultural and protected natural vegetation compete. The zone also includes two very contrasting margins and hence the map is illustrative of the main environments present along the lake shore. The map is intended to reflect the current dynamics and recent evolution of the margins of the lake in the mixed area where both fluvial and lacustrine processes coexist.

Material and methods

Aerial –photo interpretation was carried out using pairs of aerial photographs from 1976-1980 at 1:18,000 scale. Two sets of orthophotographs (0.5 m pixel) from 2006 and 2009 were analyzed and used for the subsequent field inspection which was undertaken using a GPS Trimble Geoexplorer 2008 series GEO-XT. Special attention was paid to the morphological and sedimentary nature of the lake shorelines (texture, geometry of sedimentary bodies, surface observable facies, etc.). The resulting geomorphological map obtained from the stereoscopic analysis was scanned at 600dpi together with the historic photographs and georeferenced in a geographic information system (GIS) using 25-30 control points and a RME error of < 2 m. The geomorphological map was digitized using the 2006 ortophotographs as base map.

The following geological and topographical maps were integrated in the GIS (ArcGis v10): 1) Geological map, digital version, 1: 25,000 scale (CHE, 2003), 2) Topographic map at 1:5000 scale (and detailed topography at 1:2000 scale provided by CHE), and 3) Digital terrain model SIGOE (from a 1997 flight) with a pixel of 20 m and 4 m of accuracy, 4) Landsat 5TM satellite images from humid (1992-09-02) and dry (2000-01-12) periods. The satellite images, despite their limited resolution (30-m pixel), allowed verifying the fluctuations of the water level and the extreme position of the lake shores during the last decades.

General lake morphology

The Gallocanta lacustrine depression shows significant differences between the NE and SW margins. The average difference in height between the present lake bottom and the low peripheral relieves surrounding the lake is 100 m in the northern margin and 15 m in the southern one (Fig. 2).

Fig. 2

The lake planform has three main morphological sectors: the subcircular northern one (Lagunazo de Gallocanta), the central one (Lagunazo Grande) and the palustrine southern one (Los Lagunazos). The central sector of Gallocanta Lake (5 km long and 2 km wide) shows the largest and best developed coastal landforms produced by waves and longshore currents which propagate toward the SE. The lake shores are affected by water fluctuations operating at seasonal to decadal scales (Rodó et al., 2002).

Alluvial landforms consist on stepped alluvial terraces, pediments and fans sloping towards the lake, indicating lake level fluctuations. Sedimentary forms and deposits in the lake shore are primarily related to wave action and, subsequently, to longshore currents. The intensity of sedimentary processes depends on wave energy, which is controlled by the effective fetch of the lake. The maximum effective length in Gallocanta Lake was estimated to be 7.14 km (Gracia, 1995).

Late Quatemary lake level fluctuations gave rise to 4 lacustrine terrace levels (Gracia, 1995). The sedimentological and palynological analysis of lake sediments from boreholes shows different stages of lake evolution, mainly related to climatic changes (Luzón et al., 2007). During its evolution, the Gallocanta Lake has undergone a progressive segmentation due to the growth of paired and cuspate littoral spit bars, a common process in elongated lakes oriented parallel to the dominant wind direction. In the XIX century, the maximum extent of the lake was estimated to be 1800 ha and 4 m deep (Perez and Roc, 1999) whereas in 1974 the main extent was of 1505 ha and, at present, is 500 ha (CHE, 2003).

Landforms related to lake level fluctuations (central sector)

Historical data and photographs show how several shoreline forms are abandoned during dry periods or flooded in wet periods. Aerial photographs allowed the comparison of shoreline forms between a low-level stage (e.g., 1956) and a high-level stage (e.g., 1978). Satellite Landsat images from 1992 and 2000 (Fig. 3) illustrate the highest and lowest water levels of the lake from 1984 (the operational beginning of Landsat 5TM satellite) documented by CHE (2005).

Water level fluctuations mainly affect the southern shore due to the lower incline of the lake floor in this margin, producing a greater coastal advance or retreat.

A lake level fall produces lake contraction and coastal emersion, which is especially visible in the SW shore, where sublittoral longitudinal sand bars emerge and enclose several coastal lagoons. Sediment supplied by the southern river is trapped in the lagoons, promoting a progressive shallowing of the SW lake shore. Meanwhile, the NE shore, with a higher coastal slope and almost no sediment supply, does not record significant changes apart from the partial emergence of lacustrine beaches.

A water level rise in the lake commonly produces coastal flooding and locally shoreline erosion. The SW coast records a renewed immersion of the bars previously emerged. No landward migration of the bars has been detected in the aerial photographs and images analyzed due to lake level rise. Field inspection suggests that the lagoon, active in the former high water period, is being rapidly filled with sediments supplied by the southern river, promoting its progressive emersion.

Fig. 3

As a balance of these processes, the location of the deepest area at the lake bottom experiences a significant shifting to the NE, where the deepest and most erosive currents occur, enhancing coastal erosion and beach retreat. In that zone, a new scale for the monitoring of the lake level has been recently installed.

Conclusions

Comparison among aerial photographs taken in different years, combined with satellite imagery and field inspection give important clues about the present processes and trends acting in Gallocanta lake shore. Relative water level fluctuations constitute the prime triggering factor in promoting coastal emersion or shoreline flooding/retreat. The location of the main sediment fluvial supplies in the SW margin controls shoreline migration and transformation of sublittoral environments into supralittoral and alluvial ones, by means of sedimentary infill of former coastal lagoons. A direct consequence of this process is the shifting of the deepest zones to the opposite side of the lake, enhancing shoreline erosion at the NE margin. Only a very detailed geomorphological mapping of the lake shores by means of photographs taken during flood and dry periods can give an approximate idea of all these processes, which can be afterwards recognized during field work. Additionally, the extreme flatness of the lake bottom and shores makes it quite difficult to deduce such a set of processes by simple field inspection without the help of a detailed historical remote sensing analysis.

Software

The map has been digitized and managed using ESRI ArcGis 10 software (and edited using Illustrator CS5). The different covers were edited using ArcView v.3.2 and ESRI ArcGis v.10. Satellite images were georeferenced using Erdas Imagine v.10.

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Figure legends

Fig. 1 Geological map of the study area (modified from CHE, 2003).

Fig. 2 Topographical map (left) and slope map derived from SIGOE DEM (right) showing the dissymmetrical morphology of Gallocanta Basin with respect to the NW-SE structural trends in the region. In figure on the right, the lighter the colour, the higher the slope.

Fig. 3 Colour composition RGB 543 Landsat 5 TM images of the central sector of Gallocanta lake showing extreme water levels during the last decades: maximum inundation registered in 02/09/1992 (left), and one of the driest periods in 08/03/2000 (right). Identifiable landforms are indicated.

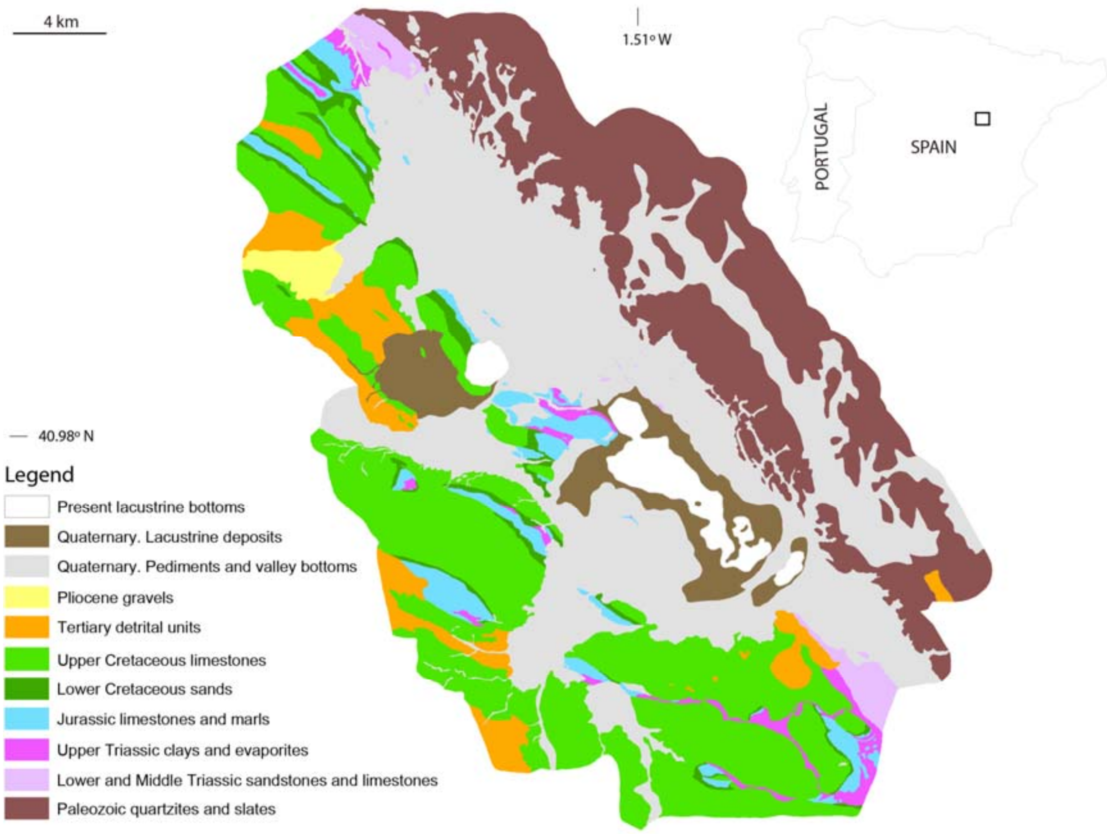


Figure 1

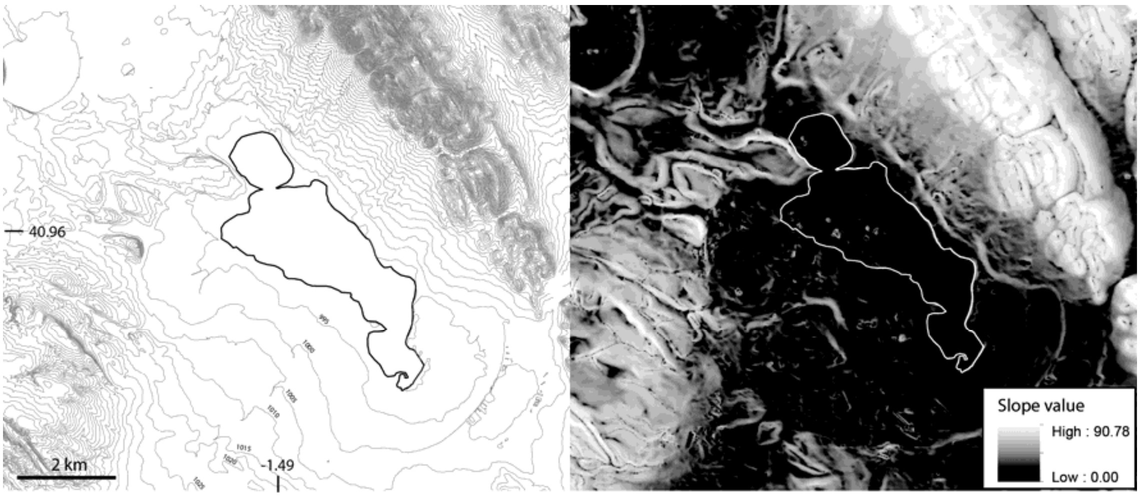


Figure 2

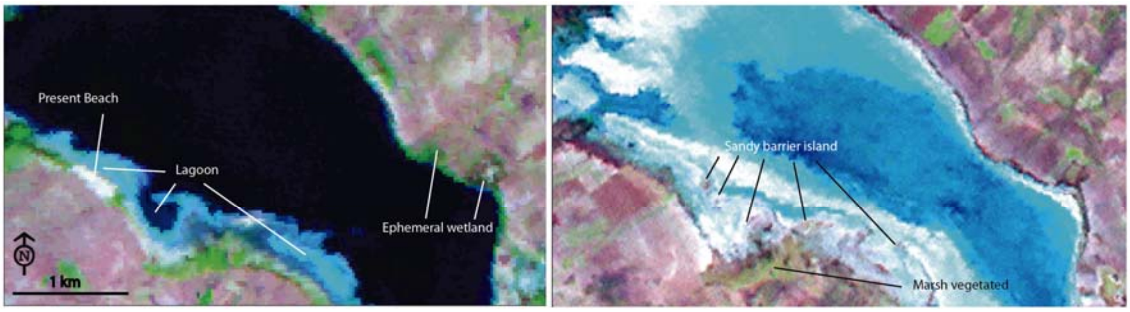
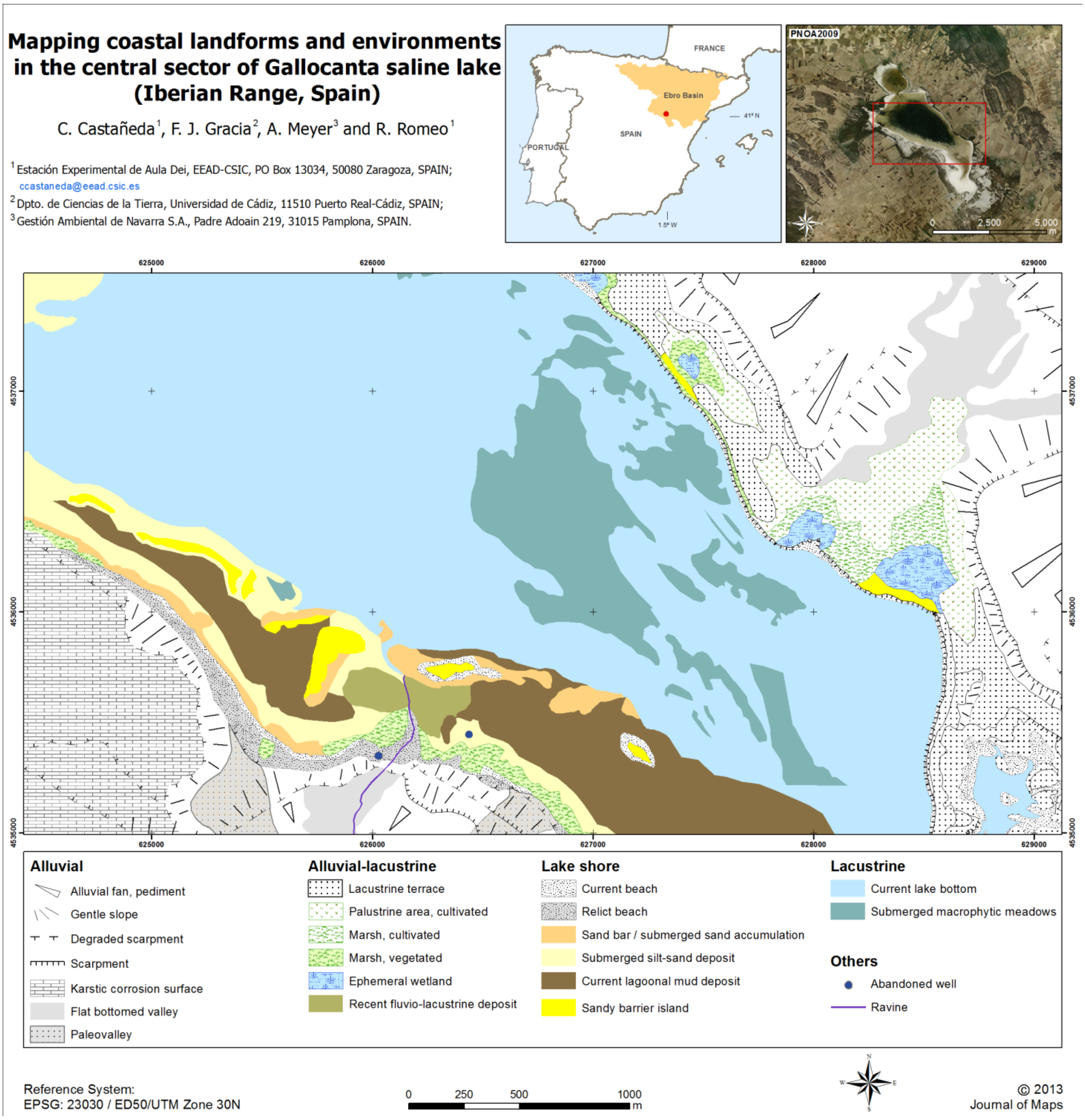


Figure 3



MAP PREVIEW